

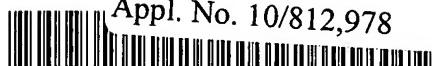


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(54) Advanced illumination system for use in microlithography

(57) A system for microlithography comprises an illumination source; an illumination optical system including, in order from an objective side, (a) a first diffractive optical element that receives illumination from the illumination source, (b) a zoom lens, (c) a second diffractive

optical element, (d) a condenser lens, (e) a relay lens, and (f) a reticle, and a projection optical system for imaging the reticle onto a substrate, wherein the system for microlithography provides a zoomable numerical aperture.

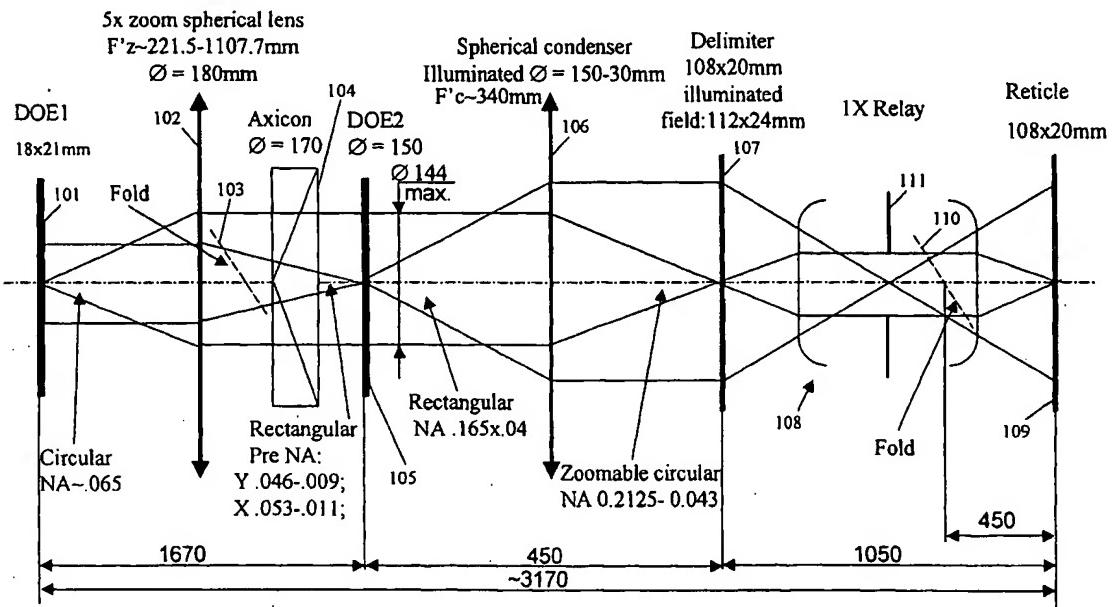


FIG. 1

Description**BACKGROUND OF THE INVENTION**5 **Field of the Invention**

[0001] The present invention relates to microlithography, and more particularly, to illumination systems for micro-lithographic equipment that have high numerical apertures.

10 **Related Art**

[0002] Photolithography (also called microlithography) is used for manufacturing of semiconductor devices. Photolithography uses electromagnetic radiation, such as ultraviolet (UV), deep UV or visible light to generate fine patterns in a semiconductor device design. Many types of semiconductor devices, such as diodes, transistors, and integrated circuits, can be fabricated using photolithographic techniques. Exposure systems or tools are used to implement photolithographic techniques, such as etching, in semiconductor fabrication. An exposure system typically includes an illumination system, a reticle (also called a mask) containing a circuit pattern, a projection system, and a wafer alignment stage for aligning a photosensitive resist-covered semiconductor wafer. The illumination system illuminates a region of the reticle with a preferably rectangular slot illumination field. The projection system projects an image of the illuminated region of the reticle circuit pattern onto the wafer.

[0003] As semiconductor device manufacturing technology advances, there are ever increasing demands on each component of the photolithography system used to manufacture the semiconductor device. This includes the illumination system used to illuminate the reticle. For example, there is a need to illuminate the reticle with an illumination field having uniform irradiance. In step-and-scan photolithography, there is also a need to vary a size of the illumination field so that the size of the illumination field can be tailored to different applications and semiconductor die dimensions.

[0004] Some illumination systems include an array or diffractive scattering optical element positioned before the reticle. The scattering optical element produces a desired angular light distribution that is subsequently imaged or relayed to the reticle.

[0005] Additionally, commonly-used die dimensions are 26x5 mm, 17x5 mm, and 11x5 mm. Thus, a standard zoom lens needs to accommodate variation in the size of the illumination field. However, a particular problem arises in the field of microlithography, where different features that are required to be formed on the semiconductor substrate require variable partial coherence on the part of the exposure optics. Specifically, partial coherence (σ), which in microlithography is commonly defined as the ratio of a numerical aperture of the illumination optics and a numerical aperture of the projection system, needs to vary depending on the nature of the feature being formed on the semiconductor substrate, e.g., the σ for trench formation may be different from the σ for line formation.

[0006] Accordingly, a need exists for a simple microlithographic system that can vary the partial coherence parameter over a large range, while simultaneously being able to accommodate different field sizes.

SUMMARY OF THE INVENTION

[0007] The present invention is directed to a microlithographic system that has variable partial coherence and field size.

[0008] One advantage of the present invention is being able to provide a microlithographic system with continuously adjustable partial coherence and discretely adjustable field size.

[0009] Another advantage of the present invention is being able to provide a microlithographic system where both partial coherence and field size can vary continuously.

[0010] Another advantage of the present invention is being able to provide a microlithographic system that can achieve the above objectives with the use of simple optics.

[0011] Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

[0012] To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, there is provided a system for microlithography comprising an illumination source; an illumination optical system including, in order from an objective side, (a) a first diffractive optical element that receives illumination from the illumination source, (b) a zoom lens, (c) a second diffractive optical element, (d) a condenser lens, (e) a relay lens, and (f) a reticle, and a projection optical system for imaging the reticle onto a substrate, wherein the system for microlithography provides a zoomable numerical aperture.

[0013] In another aspect of the present invention there is provided a system for microlithography comprising an illumination source, an illumination optical system that receives illumination from the illumination source, and a projection optical system that receives illumination from the illumination system, wherein a ratio of a numerical aperture of the illumination system and a numerical aperture of the projection optical system is continuously variable while a field size is discretely variable.

[0014] In another aspect of the present invention there is provided an illumination system for microlithography comprising, in order from an objective side a first diffractive optical element, a zoom lens, a second diffractive optical element having a rectangular numerical aperture, a condenser lens, and a relay lens.

[0015] In another aspect of the present invention there is provided a system for microlithography comprising an illumination system including, in order from an objective side, (a) a zoom lens having a first diffractive optical element on a first side, and a second diffractive optical element on a second side, (b) a condenser lens, and (c) a relay lens, and a projection optical system, wherein a ratio of a numerical aperture of the illumination system and a numerical aperture of the projection optical system is continuously variable.

[0016] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute apart of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention. In the drawings:

- FIG. 1 is a schematic illustration of one embodiment of the present invention;
- FIG. 2 is another illustration of the embodiment of FIG. 1, showing the lens arrangement;
- FIG. 3 is a schematic illustration of another embodiment of the present invention;
- FIGs. 4A-4C are a ray trace diagrams illustrating a condenser lens used in an embodiment of the present invention;
- FIGs. 5A-5B are a ray trace diagrams illustrating a relay lens used in an embodiment of the present invention;
- FIGs. 6A-6B are a ray trace diagrams illustrating a zoom lens used in an embodiment of the present invention;
- FIG. 7 illustrates an overall design of the illumination system, such as that shown in FIG. 1;
- FIG. 8 is a photograph showing a changer mechanism for a diffractive optical element;
- FIG. 9 is a photograph illustrating a dynamic adjustable slit used in the embodiment of FIG. 7; and
- FIG. 10 is a photograph illustrating the field framing assembly used in the embodiment of FIG. 7.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

[0019] In recent years, photolithography used in semiconductor device fabrication has been moving to gradually shorter wavelengths, as device features shrink in size. With feature sizes shrinking to sub-micron- and sub-0.1 μ range, semiconductor manufacturers have had to shift to the use of ultraviolet light, and in some cases to soft X-ray lithography (or deep UV). For example, excimer lasers, which emit light in the 248, 193 and 157 nm range, are increasingly used in semiconductor device fabrication. The illumination source in modern microlithographic equipment, as noted above, is typically a visible light laser, an excimer laser, or possibly a soft X-ray source. (The terms "light" and "illumination" will be used interchangeably hereafter to refer to any electromagnetic radiation used for photoresist exposure.) The use of these wavelengths presents a particular challenge to the designer of semiconductor manufacturing equipment, and especially the optics used to focus and shape the beams from the excimer lasers. In the present invention, fused silica glass is preferred for 248 and 193 nm sources, while 157 nm sources typically require optical elements made of calcium fluoride or barium fluoride to effectively focus and shape the beam.

[0020] The embodiments described utilize both refractive and reflective optical elements. It will be understood by one of ordinary skill in the art, however, that the use of reflective surfaces is frequently dictated by engineering and design concerns, rather than fundamental principles of the invention. It is therefore understood that in the description that follows, the use of reflective (folding) optical elements is needed strictly due to engineering design choices, and their use is not required in order to practice the invention.

[0021] FIG. 1 illustrates a basic configuration of one preferred embodiment of the present invention. It will be appreciated that in the figures that follow, where appropriate, the dimensions are in millimeters.

[0022] As may be seen in FIG. 1, this embodiment of the present invention includes a diffractive optical element 101 (DOE1), which is illuminated by an illumination source (not shown).

[0023] The first diffractive optical element 101 may be any element commonly used to produce diffraction, such as

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2-D array of spherical microlenses, a Fresnel lens, a diffraction grating, etc.

[0024] From a system perspectives as illustrated in FIG. 1, the numerical aperture of the beam after the first diffractive optical element 101 is approximately 0.065.

[0025] As may be further seen from FIG. 1, after passing through the first diffractive optical element 101, the beam
5 then illuminates a zoom lens 102. In the this embodiment, the zoom lens 102 is a 5x zoom spherical lens, with a focal length of 221.5-1107.7 mm. The diameter of the beam at this point is 180 mm. The zoom lens 102 is further illustrated in FIG. 6. It will be appreciated by one of ordinary skill in the art that the zoom lens 102 can use more or fewer elements, as required. One (six element design) is illustrated by the following prescription (a CODE V output):

10 RDY THI GLA.
> OBJ: INFINITY INFINITY
15 STO: INFINITY 8.000000
2: -25.24705 5.000000 'CaF2'
20

25

30

35

40

45

50

55

3: 55.68759 16.548834

4: -48.92714 25.342815 'CaF2'

5
ASP:

K : 1.779039 KC : 0

10 IC : YES CUF: 0.000000 CCF: 100

A :0.146865E-05 B :0.705843E-08 C :-823569E-11 D :0.127469E-13

AC : 0 BC : 0 CC : 0 DC : 0

15

5: -36.47260 194.914260

6: 170.18706 28.207990 'CaF2'

20

7: 510.72551 17.527333

8: 141.82233 51.966932 'CaF2'

25

9: -277.74471 12.376464

ASP:

K : -3.017335 KC : 0

30 IC : YES CUF: 0.000000 CCF: 100

A :0.913504E-07 B :-173047E-11 C :-291669E-15 D :0.148478E-19

AC : 0 BC : 0 CC : 0 DC : 0

35

10: -297.59579 10.000000 'CaF2'

11: 143.26243 1101.010134

40

12: -352.19780 11.373314 'CaF2'

13: -154.19122 187.731924

ASP:

45

K : -500.000000 KC : 0

IC : YES CUF: 0.000000 CCF: 100

50

A :-125463E-05 B :0.451681E-09 C :-724157E-13 D :0.418162E-17

AC : 0 BC : 0 CC : 0 DC : 0

55

IMG: INFINITY 0.000000

SPECIFICATION DATA

5	EPD	27.66000		
	DIM	MM		
	WL	157.63		
10	XAN	0.00000	0.00000	0.00000
	YAN	0.00000	1.85600	3.71900
	WTF	3.00000	2.00000	2.00000
15	VUY	0.00000	0.00000	0.00000
	VLY	0.00000	0.00000	0.00000

20

REFRACTIVE INDICES

25	GLASS CODE	157.63
	'CaF2'	1.558739

30

ZOOM DATA

		POS 1	POS 2	POS 3
35	VUY F1	0.00000	0.00000	0.00000
	VLY F1	0.00000	0.00000	0.00000
	VUY F2	0.00000	0.00000	0.00000
40	VLY F2	0.00000	0.00000	0.00000
	VUX F1	0.00000	0.00000	0.00000
	VLX F1	0.00000	0.00000	0.00000
45	VUX F2	0.00000	0.00000	0.00000
	VLX F2	0.00000	0.00000	0.00000
50	THI S5	194.91426	1.00000	1.00000
	THC S5	0	0	0
	THI S7	17.52733	86.68062	1.45028

55

	THC S7	0	0	0
5	THI S9	12.37646	137.13744	222.36778
	THC S9	0	0	0

10	POS 1	POS 2	POS 3
----	-------	-------	-------

INFINITE CONJUGATES

15	EFL	221.5400	664.6200	1107.7000
	BFL	164.6663	35.0875	11.1078
	FFL	115.3771	610.2350	1583.8486
20	FNO	8.0094	24.0282	40.0470
	IMG DIS	187.7319	187.7319	187.7319
	OAL	1482.2681	1482.2681	1482.2681

PARAXIAL IMAGE

25	HT	14.4001	43.2004	72.0006
	ANG	3.7190	3.7190	3.7190

ENTRANCE PUPIL

30	DIA	27.6600	27.6600	27.6600
	THI	0.0000	0.0000	0.0000

EXIT PUPIL

35	DIA	53.1110	30.1251	19.3446
	THI	590.0538	758.9393	785.8026
40	STO DIA	27.6600	27.6600	27.6600

45 [0026] As further illustrated in FIG. 1, a fold (mirror) 103 may be used in this embodiment to manage and reduce overall tool size by folding the optical path. As noted above, the use of a mirror 103 is optional, and is generally dictated by engineering/design choices.

[0027] After reflecting off the fold mirror 103, the beam then illuminates an axicon 104 (working diameter of 170 mm). After passing through the axicon 104, the beam has a rectangular numerical aperture of 0.046-0.009 in the Y dimension, and 0.053-0.011 in the X dimension.

50 [0028] After passing through the axicon 104, the beam then passes through the second diffractive element (DOE2) 105. The second diffractive element 105 is preferably a binary diffractive array. One example is a array of cylindrical micro-lenses. The specification for the second diffractive optical element 105 may be as follows:

55 Coherence length in mm, X&Y:
 248 nm temporal- no specs. spatial 0.35 x 0.15
 193 nm temporal -3, spatial 0.6 x 0.085
 X & Y beam divergence, mrad
 248nm+/-3.5x+/-3.5

193 nm +/- 1 x +/-1.75
 Beam size (nm), X & Y; 6x16; 20x20; 12x32

5 [0029] After passing through the second diffractive array 105, the numerical aperture of the beam is approximately 0.165x0.04.

[0030] The beam then passes through a spherical condenser lens 106. A condenser lens 106 usable in this embodiment can have the following characteristics:

	RDY	THI	GLA
	> OBJ: INFINITY	INFINITY	
	STO: INFINITY	75.000000	
15	2: 323.84000	5.000000	'CaF2'
	3: INFINITY	491.500000	
20	4: -145.94000	5.000000	'CaF2'
	5: 106.10000	278.500000	
	6: -2090.20000	15.000000	'CaF2'
25	7: -196.34000	50.000000	
	IMG: INFINITY	0.000000	

30 [0031] In this embodiment, the condenser lens 106 has a focal length of 340 mm (generally, it is expected that the condenser lens 106 will have a focal length of 300-400 mm), and the illuminated diameter is 150-30 mm.

[0032] After passing through the spherical condenser lens, the beam has a zoomable circular numerical aperture of 0.2125-0.043. The beam then encounters a delimiter 107 (i.e., a stop), such that the illuminated field of 112 x 24 mm becomes 108 x 22 mm. The delimiter 107 is optically conjugate with a reticle 109, through the use of a relay lens 108 (for example, a 1 X relay, or a 3X-4X relay). For design purposes, a fold 110 may be placed within the relay 108. A stop 111 is placed in the center of the relay lens 108, for a telecentric illumination system.

[0033] The relay lens 108 is used to conjugate a plane of a delimiter 107 with a plane of a reticle 109. An example of a 1X relay lens 108 prescription is shown below (here, a 10-element design):

40

45

50

55

RDY THI GLA

> OBJ: INFINITY 73.362171 AIR
5 1: 169.24669 15.000000 'NCaF2'

ASP:

K : -0.916442

10 IC : YES CUF: 0.000000

A :0.000000E+00 B :0.000000E+00 C :0.000000E+00 D
15 :0.000000E+00

2: 297.03762 280.000000

20 3: 607.71047 32.530979 'NCaF2'

4: -296.65731 1.000000

CON:

25 K : -2.313366

30 5: 172.28333 33.841572 'NCaF2'

35

40

45

50

55

6: 4765.41367 1.000000 AIR
 5
 7: 129.90270 40.919042 'NCaF2'
 8: 103.26821 29.576441
 9: -306.34576 8.000000 'NCaF2'
 10: 162.90100 15.103930
 STO: INFINITY 15.104002
 12: -162.90100 8.000000 'NCaF2'
 15: 306.34576 29.576441
 14: -103.26821 40.919042 'NCaF2'
 15: -129.90270 1.000000
 20: 16: -4765.41367 33.841572 'NCaF2'
 17: -172.28333 1.000000
 25: 18: 296.65731 32.530979 'NCaF2'
 CON:
 K : -2.313366

30
 19: -607.71047 280.000000
 20: -297.03762 15.000000 'NCaF2'
 35: 21: -169.24669 73.362171

ASP:
 K : -0.916442
 40 IC : YES CUF: 0.000000
 A :0.000000E+00 B :0.000000E+00 C :0.000000E+00 D
 :0.000000E+00
 45

50
 IMG: INFINITY 0.000000 AIR
 XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
 ADE: 0.000000 BDE: 0.000000 CDE: 0.000000

- 55 [0034] A projection optical system (not shown) images the reticle down onto the semiconductorwafer (typically reducing image size by 4x, to 26x5mm, 17x5mm, or 11x5mm).
 [0035] It will be appreciated by one of ordinary skill in the art that the use of the axicon 104 in such a system improves the system's optical properties, but the invention may work without it. It will also be appreciated by one of ordinary skill in the art that the positions of the axicon 104 and the second diffractive element 105 can be reversed (i.e., the axicon

104 may be downstream from the second diffractive element 104), although it is believed at the present time that the arrangement shown in FIG. 1 is preferred.

[0036] FIG. 2 illustrates in greater detail the arrangement of the optical elements of the illumination system. In particular; FIG. 2 shows the zoom lens 102 (shown as a 5-element design) and its constituent elements 102a, 102b, 102c, 5 102d and 102e. FIG. 2 further shows the constituent elements of the condenser lens 106 (shown here as a four-element lens), and the 1x relay 108 (shown here as an 8-element design). It further illustrates the position of the $\lambda/4$ plate, and the reticle (mask) 109, which is optically conjugate with the plane of the delimiter 107 through the relay lens 108.

[0037] FIG. 7 is another illustration of the embodiment of FIG. 1, showing additional elements commonly found in a real-life microlithography system. All the optical elements illustrated in FIG. 1 are shown in FIG. 7, using the same reference numerals. In addition, FIG. 7 also shows a changer unit 701 for the second diffractive optical element 105 (see also FIG. 8.) It is anticipated that in order to achieve different field sizes, different diffractive optical elements, having different numerical apertures, may need to be used. Accordingly, the changer unit 701 illustrated in FIGs. 7 and 8 can be used for that purpose. It will also be appreciated that a similar changer unit may be used for the first diffractive optical element 101, if necessary.

[0038] FIG. 7 also illustrates the dynamic adjustable slit 702, which is part of the delimiter 107 assembly (see also FIG. 9). The adjustable slit 702 is further described in U.S. Patent No. 5,966,202, which is incorporated by reference herein. Together with the field framing assembly 704, they are used to ensure that the proper beam size exists at the delimiter plane, which is optically conjugate with the reticle plane.

[0039] FIG. 7 also illustrates the cleanup aperture assembly 703, which is used as a telecentric stop at the center of the relay lens. (See also FIG. 10, and U.S. Patent No. 6,307,619, which is incorporated by reference herein).

[0040] FIG. 7 also illustrates the position of the $\lambda/4$ plate 112, above plane of the reticle 108 and below the last optical element (lens) of the relay lens 108.

[0041] Although the preferred embodiments of the present invention describe a system used for exposure of discrete field sizes (26x5 mm, 17x5 mm, and 11x5 mm), it is expected that the system can be made to have a continuously variable field size. This could be accomplished by the addition of other diffractive optical elements in the optical path, similar to the second diffractive optical element 105. By the addition of one or two such elements, (e.g., additional binary diffractive arrays, or cylindrical microlens arrays), which may be placed between the condenser lens and the second diffractive optical element, and by adjusting its position along the optical axis, it is possible to achieve a micro-lithographic system that has both a continuously variable partial coherence, and a continuously variable field size at the wafer.

[0042] The use of a projection optical system (not illustrated in the figures) is well-known in the art, and is typically a 4x lens that reduces the reticle image down onto the wafer.

[0043] The description of another embodiment below, and the corresponding figures, use the same reference numerals to designate the same elements as in the embodiment of FIG. 1.

[0044] FIG. 3 illustrates the basic configuration of another preferred embodiment of the present invention. As may be seen in FIG. 3, this embodiment of the present invention includes a diffractive optical element 101, which is illuminated by an illumination source (not shown).

[0045] The first diffractive optical element (DOE1) 101 maybe any refractive or reflective element commonly used to produce diffraction, such as an array of spherical microlenses, a Fresnel lens, a diffraction grating, etc. The numerical aperture of the beam after the first diffractive optical element 101 is approximately 0.065 (circular).

[0046] As may be further seen from 102, after passing through DOE1 101, light then illuminates a zoom lens 102. In this embodiment, the zoom lens 102 is a 5x zoom spherical lens, with a focal length of 196-982 mm. The diameter of the beam at this point is 135 mm. In this embodiment, the zoom lens 102 is a five-element lens.

[0047] After passing though the zoom lens 102 and reflecting off a fold mirror 103, the beam then illuminates an axicon 104. After passing through the axicon 104, the beam has a rectangular numerical aperture of 0.46-0.009 in the Y dimension, and 0.053-0.011 in the X dimension.

[0048] After passing through the axicon 104, the beam then passes through the second diffractive element (DOE2) 105 (beam diameter 135 mm). The second diffractive element 105 is preferably a binary diffractive array. One example is a array of cylindrical micro-lenses. After passing through the second diffractive array 105, the numerical aperture of the beam becomes 0.2x0.04.

[0049] The beam then passes through a condenser lens 106. In this embodiment, the condenser lens 106 has a focal length of 300 mm, and the illuminated diameter is 120-25 mm.

[0050] After passing through the spherical condenser lens, the beam has a zoomable circular numerical aperture of 0.2125-0.043. The beam then encounters a delimiter 107 (i.e., a stop), such that the illuminated field of 120 x 24 mm becomes 108 x 20 mm. The delimiter 107 is optically conjugate with a reticle 111, through the use of a relay lens 108. The relay lens 108 is used to conjugate the plane of the delimiter 107 with the plane of the reticle. For design purposes, a fold 110 may be placed within the relay lens 108. A stop 109 is placed in the center of the relay lens, for a telecentric illumination system.

- [0051] A projection optical system (not shown) images the reticle 111 down onto the semiconductor wafer (typically reducing image size by 4x).
- [0052] It will be appreciated by one of ordinary skill in the art that a relay lens is not always necessary to practice the invention, since the optical planes of the reticle and the delimiter are conjugate with each other. However, in most practical systems, a relay lens is used in order to ensure proper size of the field at the reticle plane, due to mechanical constraints.
- [0053] Additionally, it will be appreciated that the field size may also be made continuous through the use of additional second diffractive elements, similar in nature to the second diffractive element 105 described above. Alternatively, a more complex zoom lens, or the use of a second zoom lens, may be used to achieve the same purpose.
- [0054] Further, it will be appreciated that the present invention allows for the use of an even lower partial coherence σ , e.g., 0.001, if needed. A more complex zoom lens (or multiple zoom lenses) would be needed to achieve this.
- [0055] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

Claims

1. A system for microlithography comprising:
- an illumination source;
 - an illumination optical system including, in order from an objective side:
 - (a) a first diffractive optical element that receives illumination from said illumination source;
 - (b) a zoom lens;
 - (c) a second diffractive optical element;
 - (d) a condenser lens;
 - (e) a relay lens;
 - (f) a reticle; and
- a projection optical system that images said reticle onto a substrate,
- wherein said system for microlithography provides a zoomable numerical aperture.
2. The system of claim 1, wherein a field size of said system is discretely variable.
3. The system of claim 1, wherein a field size of said system is discretely variable and a ratio of a numerical aperture of said illumination optical system and a numerical aperture of said projection optical system is continuously variable.
4. The system of claim 1, wherein a field size of said system is continuously variable.
5. The system of claim 1, further including a third diffractive optical element between said second diffractive optical element and said condenser lens.
6. The system of claim 5, wherein a position of said third diffractive optical element is adjustable to continuously adjust a field size of said system.
7. The system of claim 1, wherein a ratio of a numerical aperture of said illumination system and a numerical aperture of said projection optical system is continuously variable.
8. The system of claim 7, wherein said ratio is continuously variable between about 0.2 and 1.
9. The system of claim 1, wherein said illumination source includes an excimer laser.
10. The system of claim 1, wherein said first diffractive optical element includes a microlens array.

11. The system of claim 1, wherein said first diffractive optical element includes a Fresnel lens.
12. The system of claim 1, wherein said first diffractive optical element includes a diffraction grating.
- 5 13. The system of claim 1, wherein said illumination system further includes an axicon between said zoom lens and said second diffractive element.
14. The system of claim 1, wherein said illumination system further includes an axicon between said second diffractive element and said condenser lens.
- 10 15. The system of claim 1, wherein said second diffractive optical element has a rectangular numerical aperture.
16. The system of claim 1, wherein said second diffractive optical element includes a microlens array.
- 15 17. The system of claim 16, wherein said microlens array of said second diffractive optical element includes an array of cylindrical lenses.
18. The system of claim 1, wherein said illumination system further includes a delimiter between said condenser lens and said relay lens.
- 20 19. The system of claim 1, wherein said illumination system further includes a telecentric stop centered in said relay lens.
- 25 20. A system for microlithography comprising:
 - an illumination source;
 - an illumination optical system that receives illumination from said illumination source; and
 - a projection optical system that receives illumination from said illumination system,
- 30 wherein a ratio of a numerical aperture of said illumination system and a numerical aperture of said projection optical system is continuously variable while a field size is discretely variable.
21. The system of claim 20, wherein said illumination system further includes a first diffractive optical element that receives illumination from said illumination source.
- 35 22. The system of claim 21, wherein said first diffractive optical element includes a microlens array.
23. The system of claim 21, wherein said first diffractive optical element includes a Fresnel lens.
- 40 24. The system of claim 21, wherein said first diffractive optical element includes a diffraction grating.
25. The system of claim 21, wherein said illumination system further includes a zoom lens that receives illumination from said first diffractive element.
- 45 26. The system of claim 25, wherein said illumination system further includes an axicon that receives illumination from said zoom lens.
27. The system of claim 26, wherein said illumination system further includes a second diffractive optical element that receives illumination from said axicon.
- 50 28. The system of claim 27, wherein said second diffractive optical element has a rectangular numerical aperture.
29. The system of claim 27, wherein said second diffractive optical element includes a microlens array.
- 55 30. The system of claim 27, wherein said second diffractive optical element includes an array of cylindrical lenses.
31. The system of claim 27, wherein said illumination system further includes a condenser lens that receives illumination from said second diffractive element.

32. The system of claim 27, wherein said illumination system further includes a condenser lens that receives illumination from said second diffractive element, and a relay lens that receives illumination from said condenser lens.
- 5 33. The system of claim 31, wherein said illumination system further includes a delimiter between said condenser lens and said relay lens.
- 10 34. An illumination system for microlithography comprising, in order from an objective side:
- a first diffractive optical element;
 - a zoom lens;
 - a second diffractive optical element having a rectangular numerical aperture;
 - a condenser lens; and
 - a relay lens.
- 15 35. The system of claim 34, wherein a field size of said illumination system is discretely variable.
36. The system of claim 34, further including a projection optical system, wherein a field size of said system and a partial coherence are both variable
- 20 37. The system of claim 36, wherein said partial coherence is continuously variable between about 0.2 and 1.
38. The system of claim 34, wherein said illumination system further includes an axicon between said zoom lens and said second diffractive element.
- 25 39. The system of claim 34, wherein said illumination system further includes and axicon between said second diffractive optical element and said zoom lens.
40. The system of claim 34, wherein said second diffractive optical element has a rectangular numerical aperture.
- 30 41. The system of claim 34, wherein said second diffractive optical element includes a microlens array.
42. The system of claim 34, wherein said second diffractive optical element includes an array of cylindrical lenses.
43. A system for microlithography comprising:
- 35 an illumination system including, in order from an objective side:
- (a) a zoom lens having a first diffractive optical element on a first side, and a second diffractive optical element on a second side;
 - (b) a condenser lens;
 - (c) a relay lens; and
- 40 a projection optical system,
- 45 wherein a partial coherence of said system for microlithography is continuously variable.
44. The system of claim 43, wherein a field size of said system for microlithography is discretely adjustable.
45. The system of claim 43, wherein a field size of said system for microlithography is continuously adjustable.
- 50 46. The system of claim 43, wherein said partial coherence is continuously variable between 0.2 and 1.
47. The system of claim 43, wherein said illumination system further includes an axicon between said zoom lens and said condenser lens.
- 55 48. The system of claim 43, wherein said second diffractive optical element has a rectangular numerical aperture.
49. The system of claim 43, wherein said second diffractive optical element includes a microlens array.

50. The system of claim 43, wherein said second diffractive optical element includes an array of cylindrical lenses.
51. The system of claim 43, wherein said illumination system further includes a delimiter between said condenser lens and said relay lens that receives illumination from said relay lens.
- 5 52. A method of exposing a substrate comprising the steps of:
illuminating an illumination optical system that includes, in order from an objective side:
10 (a) a first diffractive optical element that receives illumination from the illumination source;
(b) a zoom lens;
(c) a second diffractive optical element;
(d) a condenser lens;
(e) a relay lens;
15 (f) a reticle;
forming a zoomable numerical aperture beam at a plane of the reticle; and
projecting the beam formed in the plane of the reticle onto the substrate through a projection optical system.
- 20 53. The system of claim 52, further including the step of varying a field size of the illumination optical system.
54. The system of claim 52, further including the step of discretely varying a field size of the illumination optical system and continuously varying a numerical aperture of the projection optical system.
- 25 55. The system of claim 52, further including the step of continuously varying a field size of the illumination optical system.
56. The system of claim 52, wherein said illuminating step includes the step of illuminating a third diffractive optical element positioned between the second diffractive optical element and the condenser lens.
- 30 57. The system of claim 56, further including the step of adjusting a position of the third diffractive optical element to continuously adjust a field size of the system.
58. The system of claim 52, further including the step of varying a ratio of a numerical aperture of the illumination system and a numerical aperture of the projection optical system between about 0.2 and 1.
- 35 59. The system of claim 52, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a microlens array.
60. The system of claim 52, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a Fresnel lens.
- 40 61. The system of claim 52, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a diffraction grating.
62. The system of claim 52, wherein said illuminating step includes the step of illuminating an axicon positioned between the zoom lens and the second diffractive element.
- 45 63. The system of claim 52, wherein said illuminating step includes the step of illuminating an axicon positioned between the second diffractive element and the condenser lens.
64. The system of claim 52, wherein said illuminating step includes the step of illuminating the second diffractive optical element that has a rectangular numerical aperture.
- 50 65. The system of claim 52, wherein said illuminating step includes the step of illuminating the second diffractive optical element that includes a microlens array.
66. The system of claim 52, wherein said illuminating step includes the step of illuminating the second diffractive optical

element that includes an array of cylindrical lenses.

67. A method of exposing a substrate comprising the steps of:

- 5 illuminating an illumination system that includes, in order from an objective side:
- (a) a zoom lens having a first diffractive optical element on a first side, and a second diffractive optical element on a second side;
 - (b) a condenser lens;
 - 10 (c) a relay lens; and
- projecting a beam formed by the relay lens onto the wafer using a projection optical system; and continuously varying a partial coherence of an illumination optical system/projection optical system combination.
- 15 68. The system of claim 68, further including the step of varying a field size of the illumination optical system.
69. The system of claim 68, further including the step of discretely varying a field size of the illumination optical system and continuously varying a numerical aperture of the projection optical system.
- 20 70. The system of claim 68, further including the step of continuously varying a field size of the illumination optical system.
71. The system of claim 68, wherein said illuminating step includes the step of illuminating a third diffractive optical element positioned between the second diffractive optical element and the condenser lens.
- 25 72. The system of claim 72, further including the step of adjusting a position of the third diffractive optical element to continuously adjust a field size of the system.
- 30 73. The system of claim 68, further including the step of varying a ratio of a numerical aperture of the illumination system and a numerical aperture of the projection optical system between about 0.2 and 1.
74. The system of claim 68, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a microlens array.
- 35 75. The system of claim 68, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a Fresnel lens.
76. The system of claim 68, wherein said illuminating step includes the step of illuminating the first diffractive optical element that includes a diffraction grating.
- 40 77. The system of claim 68, wherein said illuminating step includes the step of illuminating an axicon positioned between the zoom lens and the second diffractive element.
78. The system of claim 68, wherein said illuminating step includes the step of illuminating an axicon positioned between the second diffractive element and the condenser lens.
- 45 79. The system of claim 68, wherein said illuminating step includes the step of illuminating the second diffractive optical element that has a rectangular numerical aperture.
80. The system of claim 68, wherein said illuminating step includes the step of illuminating the second diffractive optical element that includes a microlens array.
- 50 81. The system of claim 68, wherein said illuminating step includes the step of illuminating the second diffractive optical element that includes an array of cylindrical lenses.

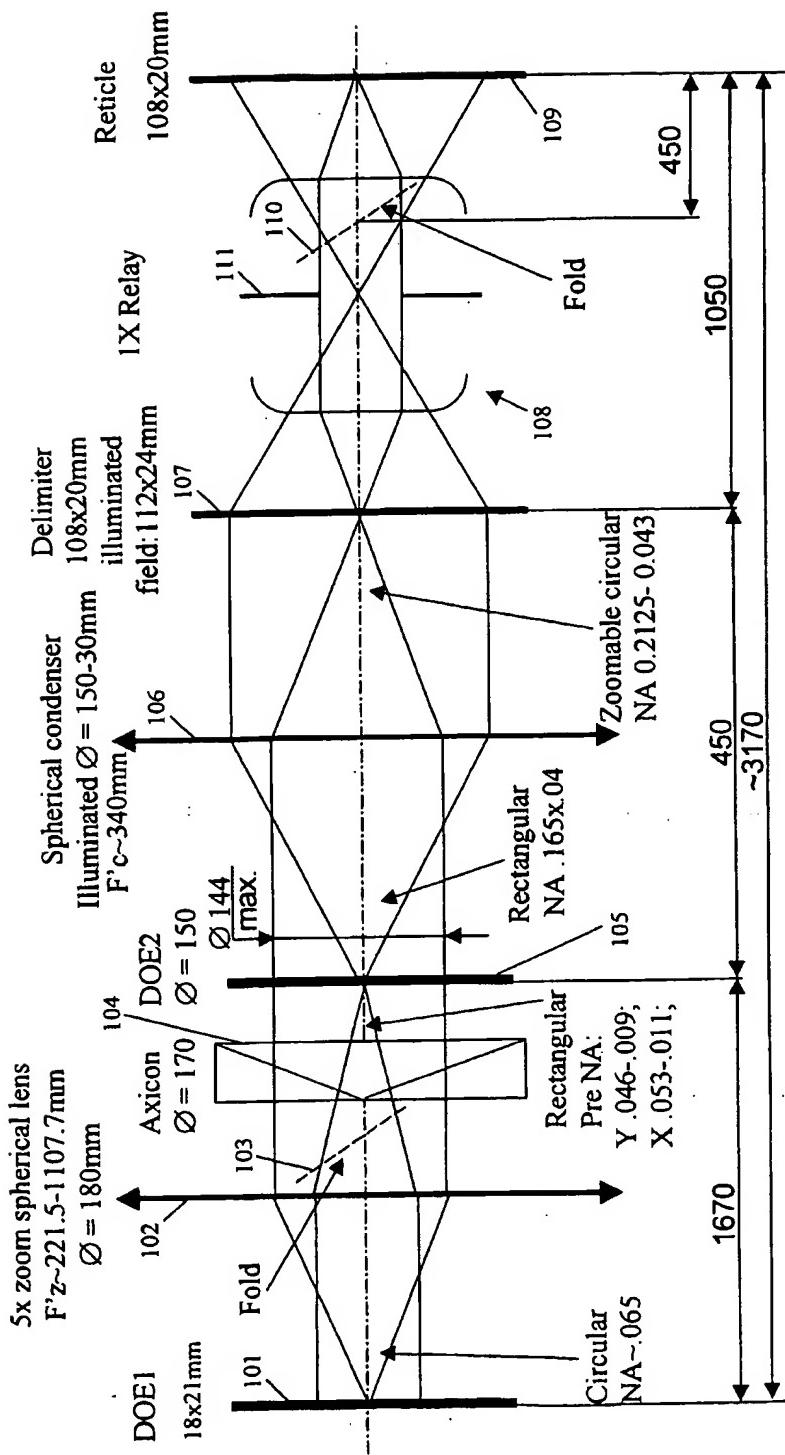


FIG. 1

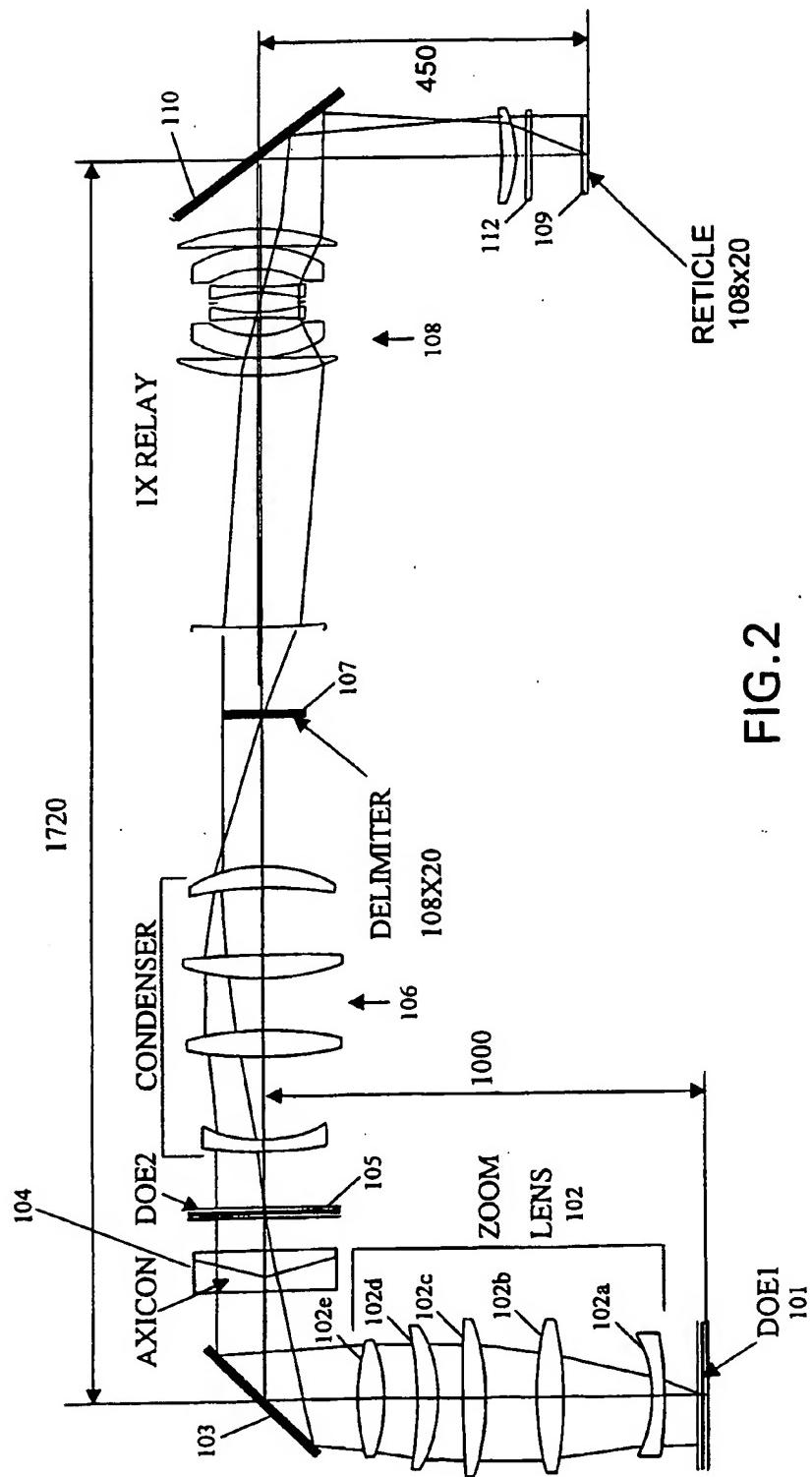


FIG.2

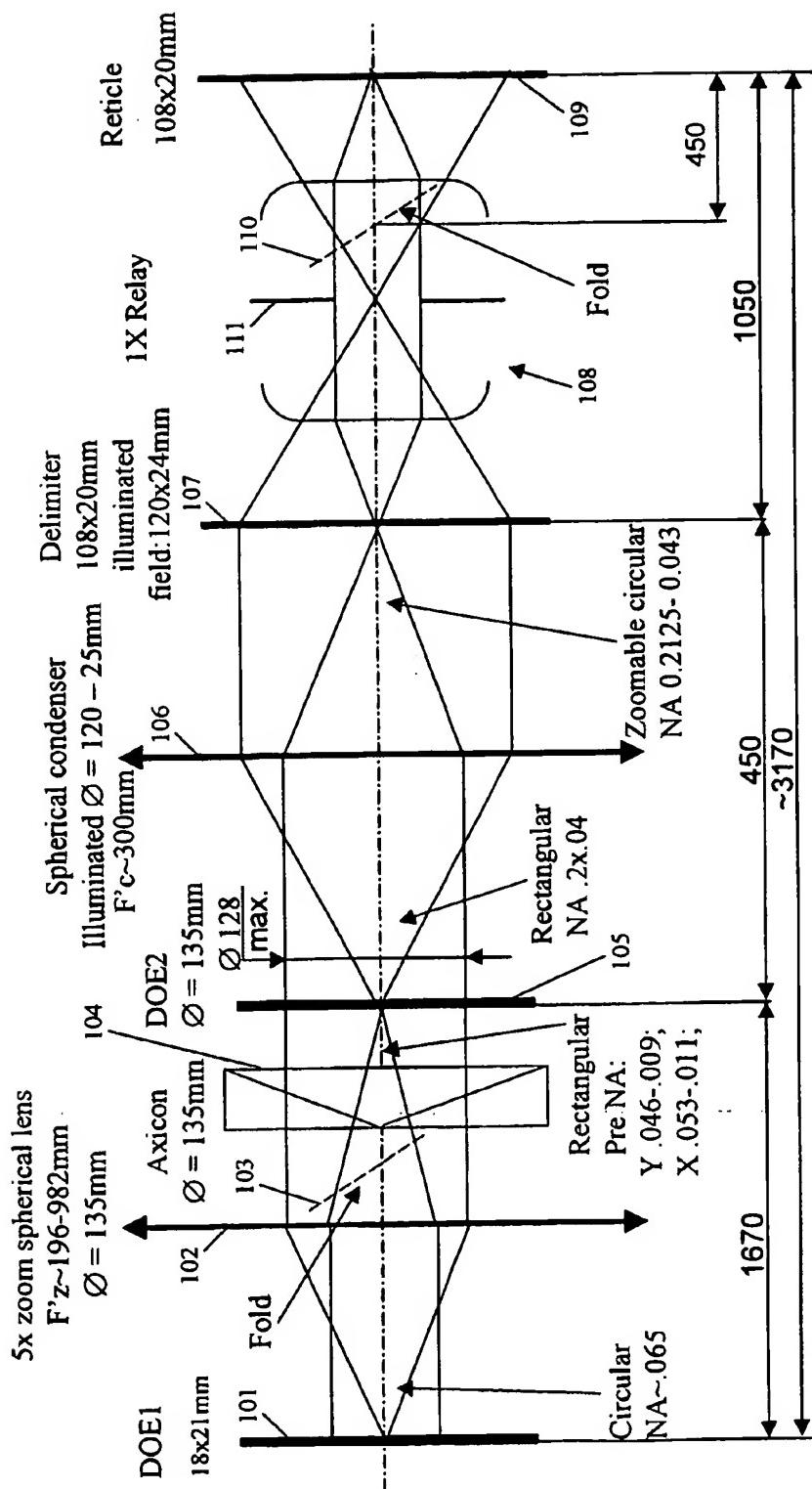


FIG. 3

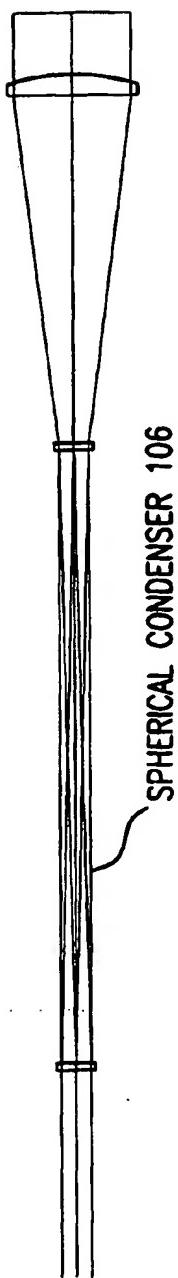


FIG. 4A

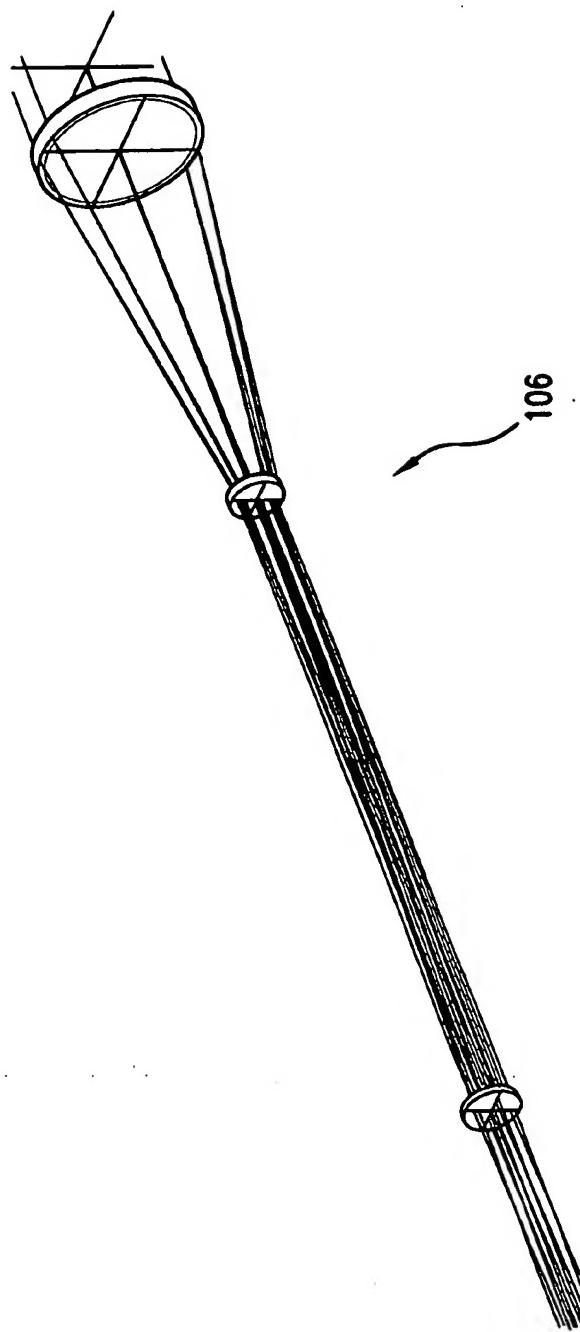


FIG.4B

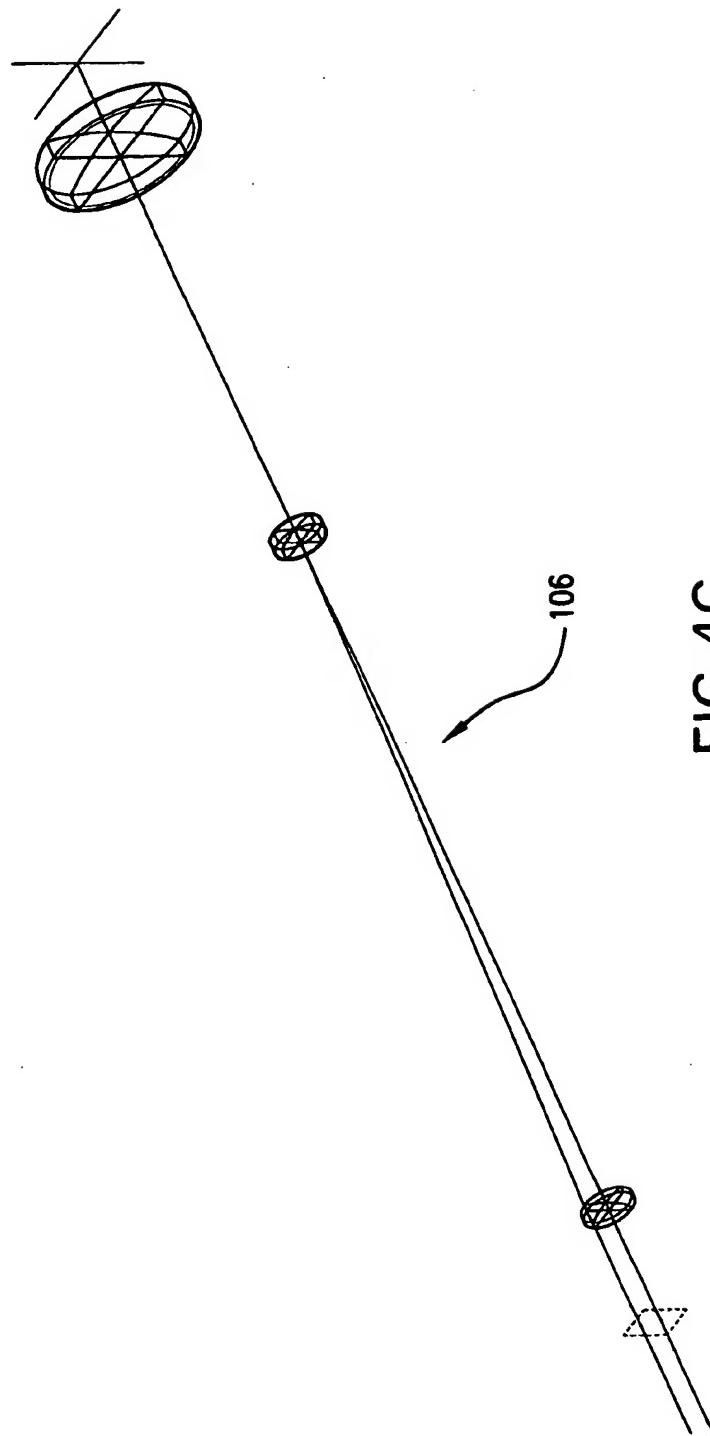


FIG. 4C

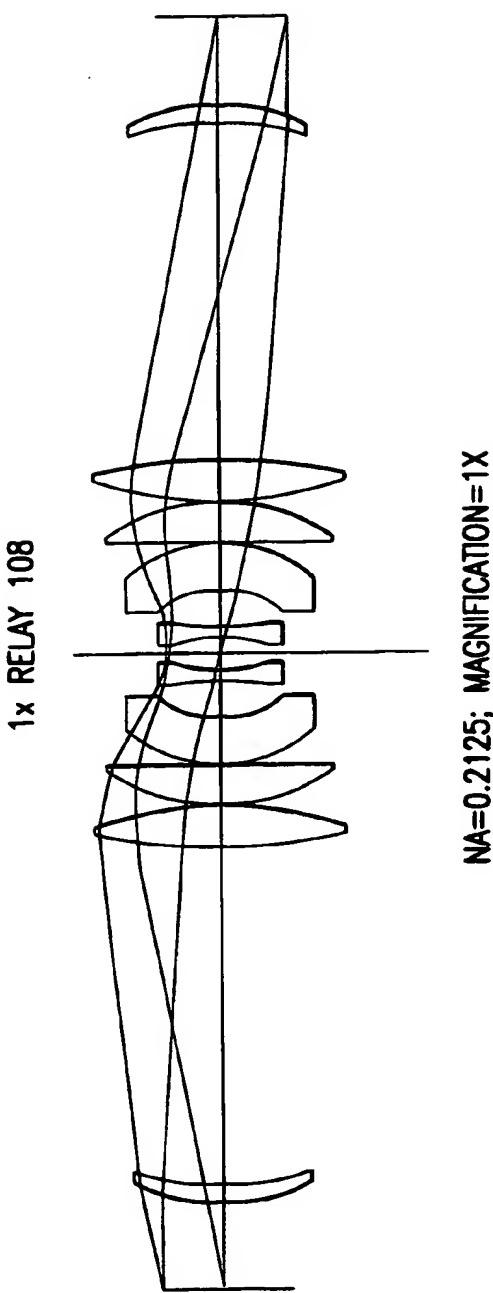
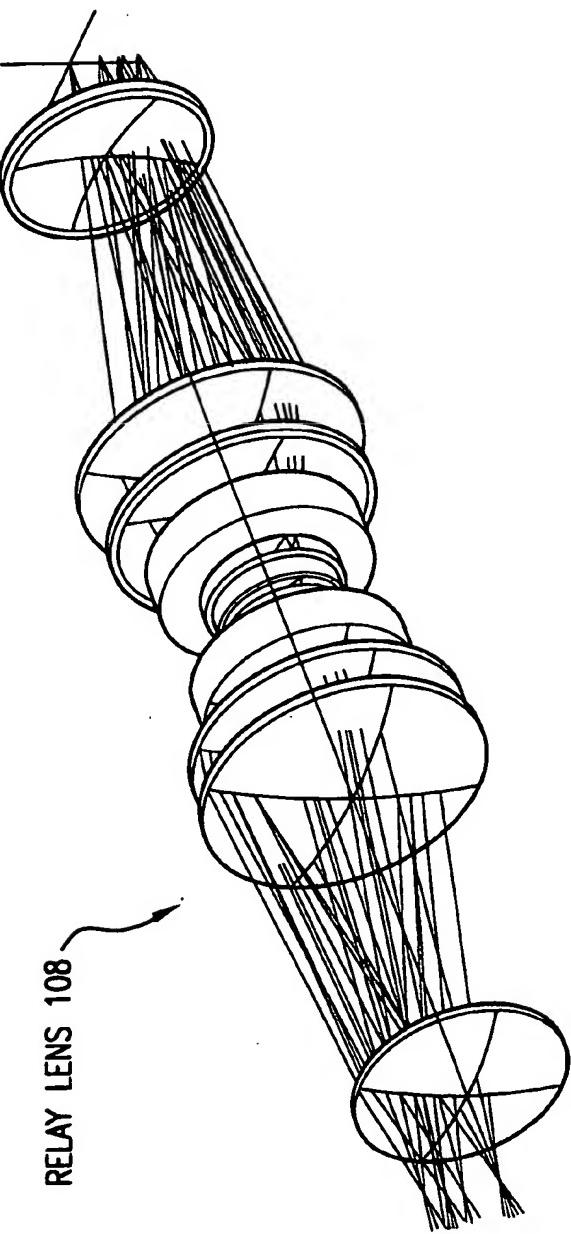
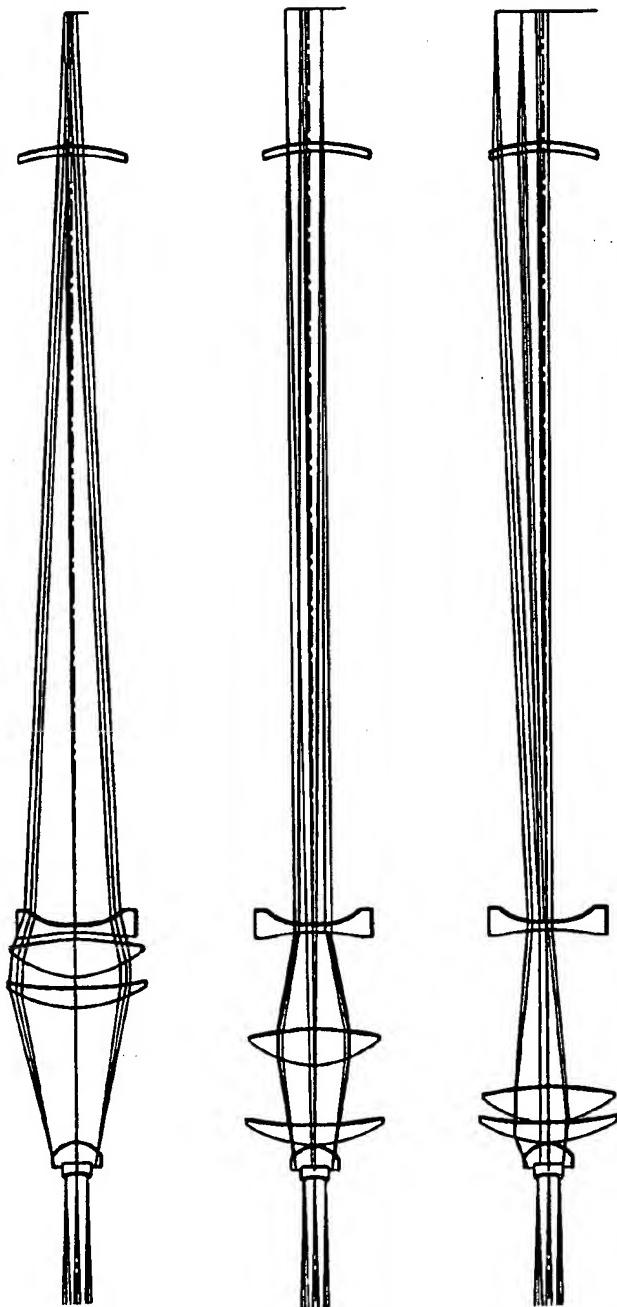


FIG. 5A



5X ZOOM LENS 102



$f'_{\min}=221.5 \text{ mm}; f'_{\max}=1107.7 \text{ mm.}$

FIG. 6A

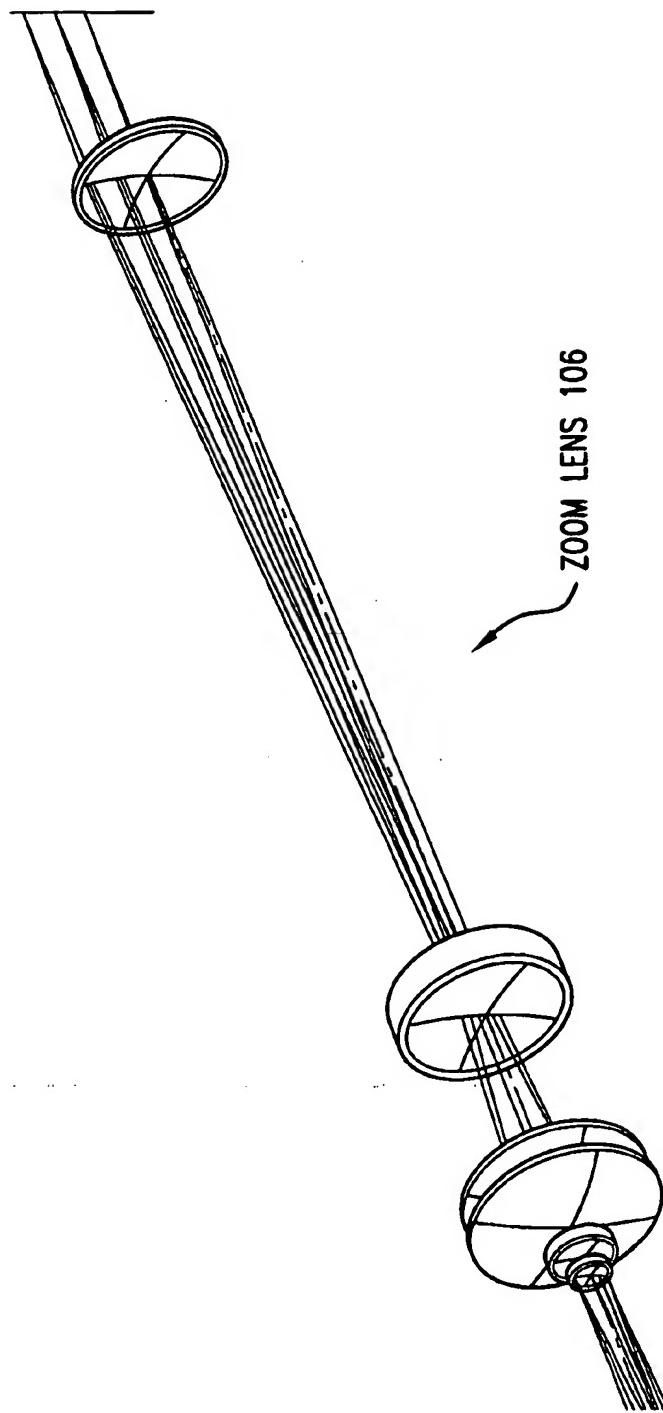


FIG. 6B

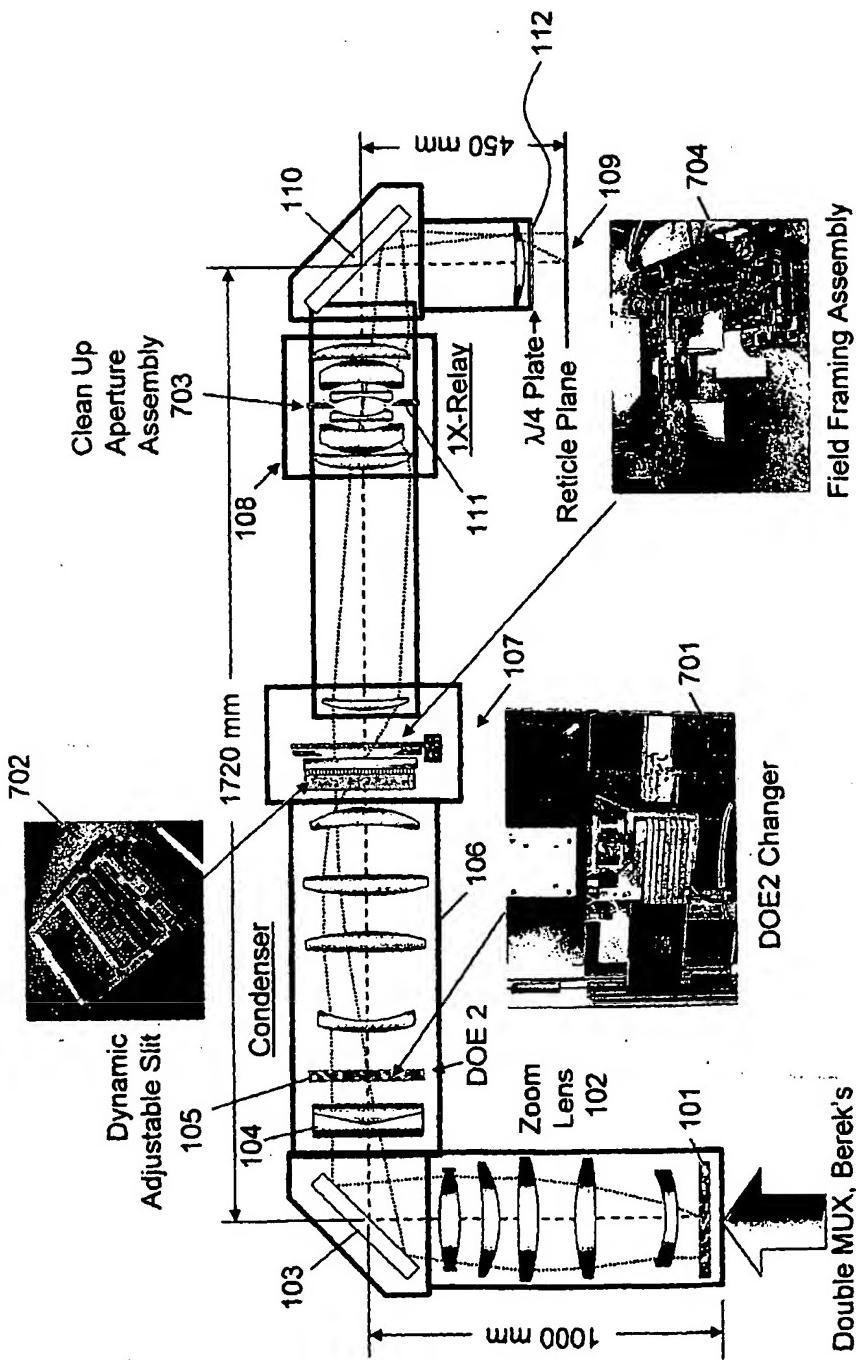


FIG. 7

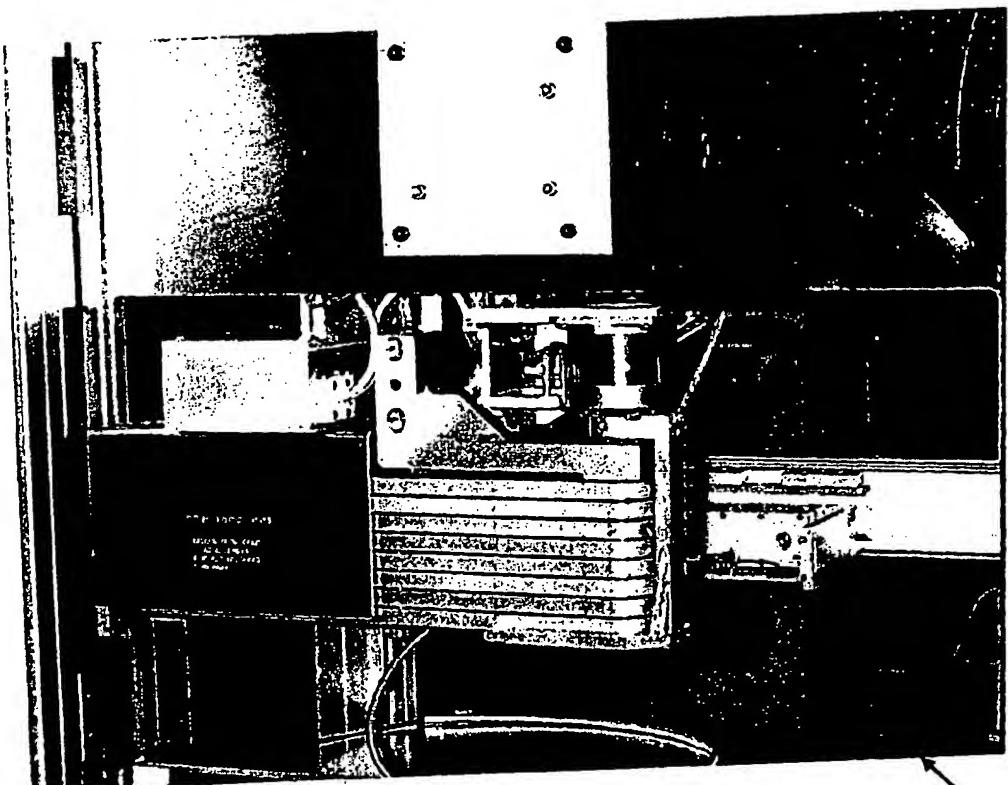


FIG. 8

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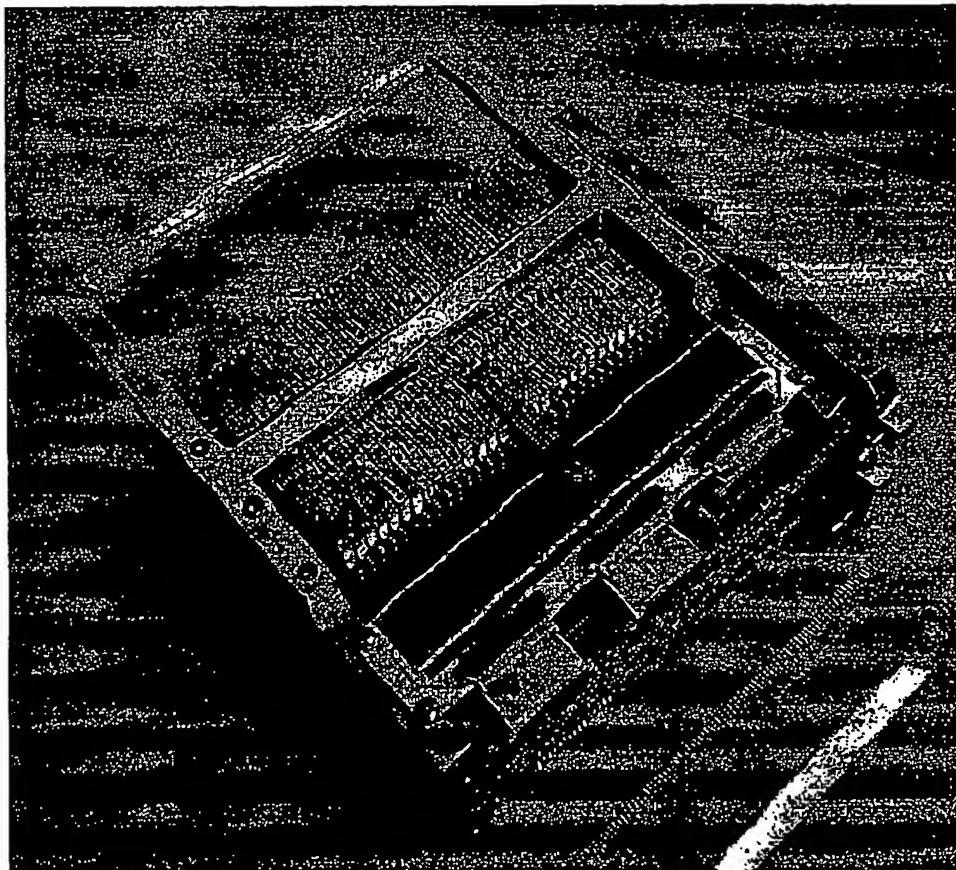
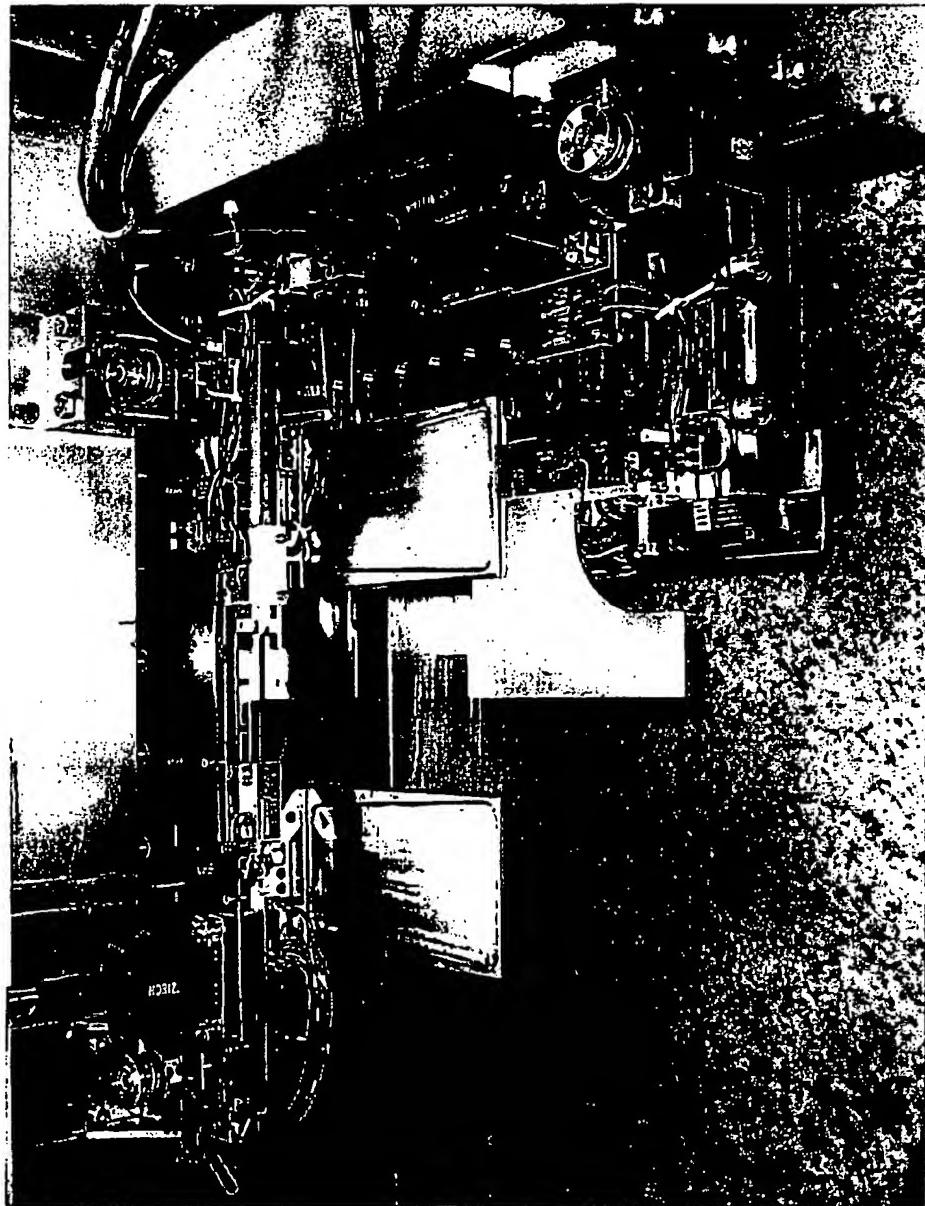


FIG. 9

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704 →

FIG. 10